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Renewable energy potential of roadside grass cuttings

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Abstract

Roadside grass verges are an important part of transport corridors and have a critical role in ensuring road user safety. However, the verges require ongoing maintenance on a regular basis throughout the growth season and throughout the design life of the transport infrastructure. The collection of the verge cuttings, which are currently left in situ, may create environmental benefits such as economic and energy benefits from biogas production. This study focuses on Scotland where there are 56,000 km of verge potential and where the grassed verges commonly receive a 1.2 m swath cut two times per year. Our investigations revealed that the potential productive land along Scotland's road network was of the order of 270×10^6 m^2. Using comparative statistical analysis, we have estimated the potential average dry mass of cuttings per kilometer to be between 300 kg and 400 kg, yielding a biochemical methane potential of 0.271 m^3 per kilogram of volatile solids added. The cautious estimate showed that potentially 18.2×10^6 m^3 methane (CH_4) could be produced, while, in the best-case scenario, up to 24.3×10^6 m^3 CH_4 may be produced through regular maintenance of the grass verge strips in Scotland. Cost-benefit analysis showed that considering the availability of cutting machinery and a potential increase in the swath cutting to 1.6 m would potentially yield between 24.3 $\times 10^6$ - 32,4 $\times 10^6$ m^3 CH_4. The sustainable treatment of cuttings arising can promote a healthy roadside verge environment and can reduce greenhouse gas emissions as Scotland looks to achieve their 80% emission target by 2050.

Keywords: Renewable energy; Grass cuttings; Biogas production; Energy from waste; Sustainability

1. Introduction

The sustainable management of grass cuttings from roadside verges in Scotland is an area that requires further consideration [1]. There can be issues with grass cuttings left lying on the verge, which look unsightly and supress desirability, healthy growth of native flora but also, conversely, will add excess nitrogen into the soil and encourage accelerated grass growth, placing more burden on maintenance costs. Additionally, grassed verges along Scotland's 56,000 km of road network have become a valuable ecological refuge. However, currently, Scottish local authorities must be more efficient as public expenditure decreases with an expected 17 % gap between the cost of providing essential services and the availability of council funding by 2020/21. Typically, grassed verges and public and open spaces are likely to be hit hardest from such cuts; therefore the collection and processing of grass cuttings along Scotland's road network to produce biogas can potentially reduce the burden on local council budgets. If grass cuttings were to be considered a resource opposed to waste, not only would verge cuttings generate sustainable renewable energy, it would also have a positive impact on the verge network environment.

The bio-energy stored in verge grass has been previously considered for its potential and this paper looks to investigate the extent of the available resource to Scotland [2, 3]. This study looks to investigate and determine the potential productive land along Scotland's road network of ca. 270×10^6 m^2. This compares to the Living Highways report which highlighted the dry mass per km to be between 300 – 400 kg, yielding a biochemical methane potential of 0.271 m^3 methane (CH_4) per kilogram of volatile solids added.

In general, rural roads across Scotland will receive one to two cuts per annum with additional cuts required at roundabouts and junctions that ensure road user safety. Similarly, urban amenity cuts beside roads can be over ten meters deep and may receive up to 18 cuts during the growing season. Current verge management plans are to leave cuttings in-situ due to both a lack of trial data, and the upfront cost to implement cut and collect technology. Moreover, the lack of anaerobic digestion (AD) plants across Scotland and the travel distance for collection and deposition may deter further investigation; yet AD plants are becoming increasingly common on farms from the mainland to the islands, viability is also further reinforced through improved cutting technologies with the ability to cut swaths of up to 1.6 m and increasing

Scotland's productive landmass by 90×10^6 m^2 without increasing the distance travelled.

Scotland has also set an ambitious 80% emissions reduction target for 2050, and will need to consider alternative forms of renewable energy, [4]. The production of biogas can help achieve this target while also reducing Scotland's fossil fuel usage, more so it also considers an efficient endues for the lifecycle of verge maintenance.

Fig. 1 Scotland's Road Network. Source: Mapstop

2. Problem identification and basic principle

Current grass maintenance programmes across Scottish local authorities and trunk road network contractors are to leave cuttings in-situ. Removing these cuttings would enhance roadside biodiversity value, effectively aligning lifecycle thinking with a viable renewable energy sources and preventing waste. Ultimately, steps taken now by the Scottish Government, and local authorities can produce tangible results that aid Scotland's transition to a low carbon future, creating jobs, enhancing ecological environments, and driving efficient sustainable development across Scotland [5].

The Scottish road network comprises roads, bridges, footpaths, lighting, signs, and lines (Fig. 1). Local authorities determine the priorities for landscape maintenance. Under the Roads (Scotland) Act 1984, the statutory responsibility for local roads that includes maintenance, repair, and improvement lies with local road authorities. The roads infrastructure is vital to Scotland's economic and social wellbeing, and a crucial service that underpins health, environment, and standard of life. In terms of road maintenance, the asset cannot be allowed to deteriorate and it is up to each road authority to determine how funds should be allocated towards roads maintenance that includes verge maintenance. For local roads, each local authority develops a Roads Asset Management Plan (RAMP) which provides the necessary data to carry out robust investment planning work that's based on different service levels. Scotland has 25,600 km of classified roads and 28,800 km of unclassified roads. Roads are broken down into the following classifications:

A Roads – that facilitate the connection of major transport routes between geographic regions.

B Roads – that connect A roads with less significant roads by filtering traffic across the road network.

C Roads – in general with a contrasting interest to that of more important identified roads in terms of their value to movement. Normally the function of these rural roads is to connect unclassified roads to A and B roads, but also support rural economies.

The strategic management of roadside biodiversity has also drawn serious interest from the Scottish Government; plans to include the management of roadside biodiversity within the National Ecological Network (NEN) suggests the ecological significance of roadside verges as refuges and corridors for biodiversity. More so, the loss of important greenspace across the UK has resulted in road verges becoming important natural habitats for nature conservation. Developing National Action Programs to protect ecosystem services along verges could also reduce the existing cost burden of current cutting regimes as the removal of cuttings would be required to enhance biodiversity [6]. Similarly, studies have also linked land-use change with the significant decline in natural habitats throughout the last 40 years. Moreover, Scotland's loss of open space to agricultural intensification over the last 70 years has resulted in isolated pockets of more stationary biodiversity relying on the physical links associated with the road network [7].

Conservation of roadside biodiversity must also consider the relationship between species richness and standing biomass, where an early cut has been shown to aid the flowering of plants and increasing species richness [8]. On the other hand, overgrowth and poor management of meadows will result in space and light competition, enhancement of rank vegetation, and reducing overall species richness. There is also evidence to suggest a close relationship between species richness and soil fertility where cuttings left in-situ increased nutrient levels and the growth of more dominant plants [9]. Therefore, verge management can benefit species richness through the removal of cuttings, reducing nutrient levels alongside roads [10].

If harvested, Scotland's 56,000 km of road verges would be expected to produce significant quantities of green waste that requires processing through an effective end use. In

Scotland, technologies such as anaerobic digestion (AD) plants and composting facilities are already in place to accept and convert green waste into new products, which suggests that verge cuttings should be a resource, and not a waste issue, or an extra verge management process; however this would require a change in the European end-of-waste regulations.

Anaerobic digestion of roadside grass cuttings can provide the potential to produce renewable energy and fertilizer for farms with small scale AD capacity. Largely the collection and biogas production from grassed verges has been overlooked and is possibly a result of the unknown values of element concentrations released on combustion. However, AD plants are slowly gaining momentum and have been constructed on farms over the last decade to produce renewable energy and reduce running costs [11]. Similarly, AD of manures and grasses has become more conventional as farmers look to increase biogas yields. In general, biofuels have been subject to some debate with regards to competing with good agricultural land for food [12]. However, co-digestion of verge grass cuttings with waste byproducts eliminates the issues of land for food or bioenergy and will also help reduce greenhouse gas emissions.

Modern cut and collect technologies have advanced since the Living Highways Trial. For instance, Compact Machines for Agriculture and Industries International (CAEB) offer a wide range of mini-bailers costing around £9,000 that have been specifically designed for operation on slopes, and hard to access areas. Furthermore, the CAEB Mountainpress range extends to tractor trailed applications and would enhance recovery potential from public and open spaces and even sports stadiums. Similarly, MULAG Fahrzeugwerk International (MULAG) offer innovative technologies for roadside maintenance, and have developed high-quality 1.2–1.6 m cutting attachments that can be fitted onto vehicles. A potential option may be to convert Scottish winter gritting vehicles with MULAG attachments, offering a modern integrated approach to grass collection. Similarly, the use of automatic ground sensing allows for easy cutting around roadside obstacles, and would significantly improve health and safety. Additionally, attachments are multi-functional where they can also be used by local authorities to cut hedges safely and efficient, as well as being able to switch of the cutter and efficiently collect litter. While this study's focus is on cut and collect, the multi-functional benefits of the MULAG application could have benefits for local council budgets while enhancing health and safety of workers.

In terms of renewable energy for transport, liquid biofuels are the primary source even though electrification and the use of lithium batteries continue to receive greater attention. In 2016, conventional biofuels accounted for 4% of the global transport fuels from biogas production continues to grow across the UK and Scotland as more AD plants are developed. The Scottish Biofuel Programme (closed in March 2017) offered support to companies looking to identify environmental and economic benefits from biofuels and helped the development of Scotland's biofuel sector. Furthermore, development of AD and micro AD across much of rural Scotland offers improved energy security for business and farms alike. Similarly, the purification of biogas produces liquid bio-methane and can be used as a vehicle fuel and helps Scotland meet the requirements set out in the Renewable Transport Fuel Obligation Order SI 2007/3072.

The Living Highways Project carried out in 2006 by Montgomeryshire Wildlife Trust, was designed to investigate the feasibility of the wide-scale collection of cuttings from grassed verges in Powys, Wales, UK, for biogas and compost production. Specialised harvesting machinery was hired during the trial to cut and collect a 1.2 m swath from a mix of grassed verges. Laboratory investigation of grass samples found that a conservative vegetation yield of 0.3 tonnes dry mass/km/yr was realistic, however maximum yields of 0.6 tonnes dry mass/km/yr were recorded with average yields of between 0.3–0.4 tonnes dry mass/km/yr. The trial also showed biochemical methane production to 0.27 m^3CH_4/kg volatile solids added. The overall feasibility of the study found that wide-scale collecting of cuttings was possible and would produce sufficient biogas and compost. In addition, it highlighted the environmental benefits of landfill diversion and related emissions reduction. However, future development and evaluation was still required, pinpointing improved harvesting and transportation efficiency requirements needed before a thorough economic feasibility can be assessed.

The aim of this study is to investigate the magnitude of the potential sustainable renewable energy within Scotland's roadside verges, with focus on the biogas potential, and this will be achieved through the following objectives:

- To research cutting technologies that can be used on grassed verges,
- Undertake a comparative analysis with the Living Highways Project,
- To analyse and evaluate expert opinions regarding cut and collect, both from Scotland's local authorities and Trunk Road Operators,
- To estimate the potential renewable energy locked within Scotland's grassed verges.

3. Methodology

The methods used in this study were based on comparative statistical analysis, as well as quantitative and qualitative methods such as calculations and interviews.

For the availability of roadside grass along Scotland's road network, analysis and calculations were used to determine the theoretical productive land. The calculations incorporated cutting patterns, as well as considering either side of the road network based on the statistical analysis of the Living Highways Project that highlighted the harvestable swath of UK grassed verges to be between 1–1.2 m. Also, a review of currently available cutting technologies highlighted CAEB International, and MULAG International to have efficient technologies with the ability to cut 1.2–1.6m swaths. Therefore, the verge potential was evaluated using two different scenarios to assess both 1.2 m and 1.6 m swath cuts to estimate the total potential productive land that could be harvested for biogas production. Based on these findings, the accumulated amount of dry mass and biochemical methane could be estimated.

The productive land was calculated as:

$$56{,}000km \ \times 2\ cuts \ \times 2\ (either\ side)\ \times 1.2m \qquad (1)$$

$$56{,}000km \ \times 2\ cuts \ \times 2\ (either\ side)\ \times 1.6m \qquad (2)$$

The dry biomass per kilometre was assessed as:

$$1.2m\ swath = productive\ land\ x\ kg\ dry\ mass/km \qquad (3)$$

$$1.6m\ swath = productive\ land\ x\ kg\ dry\ mass/km \qquad (4)$$

The biochemical methane potential was then evaluated:

$$1.2m\ swath = kg\ dry\ mass/km \times 0.271\ \ \text{bmp} \qquad (5)$$

$$1.6m\ swath = kg\ dry\ mass/km\ \times\ 0.271\ \text{bmp} \qquad (6)$$

Interviews were conducted with 12 out of 32 invitees to ascertain a broad cross-section of expert opinions. Biogas experts, transport authorities, local authorities, government agencies, and grounds maintenance suppliers were interviewed on the feasibility of grass cutting and biogas production. The interviewees comprised: Transport Scotland, Mouchel, Bear Scotland, Xergi Biogas, Principle Biogas, Biogas Power, Biogas Products, Renfrewshire Council, South Lanarkshire Council, SEPA, Montgomeryshire Wildlife Trust, Scottish Natural Heritage, Burgess Ground Care Equipment, and 4 Recycling Group. Questions put forward varied slightly between contacts, where biogas experts were asked if grass cuttings were a viable AD feedstock; the rest of the questions were designed around economic and environmental aspects associated with the cutting and collection of grassed verges.

4. Results

Based on the calculations in Section 3, Scotland's overall landmass accumulates to 7.8x10^6 ha; local authorities and trunk road contractors have an obligation to maintain grassed verges to a width of 1.2 m, equating to 26,874 ha of road verges. Investigation highlighted that the potential available productive landmass across Scotland's road network was of the order of 270x10^6 m^2. Therefore, verge maintenance is required on 0.034 % of Scotland's overall landmass which, however, equates to a surface area greater than Loch Lomond, and Liechtenstein combined.

Comparative statistical analysis of the Living Highways Report showed that the average dry mass/km cut was 300 – 400 kg; trials were subject to varied characteristics such as location and environmental conditions. When applied to Scotland's road networks, results showed a dry mass potential of between 67x10^6 – 90x10^6 kg. The expected dry mass yields would increase substantially if swath cuttings were increased to 1.6 m, resulting in potential yields between 90x10^6 – 119x10^6 kg of dry mass from 358x10^6 ha of potential productive land.

The biochemical methane potential was found to be 0.271 m^3 CH_4/kg when volatile solids are added. Based on this figure it was calculated that a 1.2 m swath cut across Scotland's road network would potentially produce between 18,2x10^6 and 24,3x10^6 m^3 CH_4 through cut-and-collect maintenance. In-order to provide a cost-benefit analysis, considering the availability of cutting modern technology calculations were also produced for a 1.6 m swath and results showed that a potentially biochemical yield between 24.3x10^6 - 32.4x10^6 m^3 CH_4 could be obtained (Table 1).

Table 1 Performance factors

Swath Cut	**1.2m**	**1.6m**
Landmass [m^2]	270x10^6	358x10^6
Total dry mass/km (300kg/km)	67x10^6	90x10^6
Total dry mass/km (400kg/km)	90x10^6	119x10^6
Total m^3 CH_4 (300kg/km)	18.2x10^6	24.3x10^6
Total m^3 CH_4 (400kg/km)	24.3x10^6	32.4x10^6

5. Discussions

Grassed roadside verges along the Scottish road network do not impact on food production and potentially contain between 18,2x10^6 - 24,3x10^6 m^3 CH_4 based on a 1.2 m swath; increased yields of between 24,3x10^6 - 32,4x10^6 m^3 can be potentially produced if a 1.6 m swath cutting regime is adopted. However, suitability of collecting the material must consider the interlinking purposes verges serve to reflect both the local and route location circumstances. Such functions will include: forward visibility and breakdown refuge, screening and sheltering that includes mitigation against and negative impacts of road traffic and night hours maintenance.Moreover road verge corridors have been established as ecological hot-spots for government habitat restoration projects [13].

The complete utilisation of the Scottish road network can have positive economic and environmental benefits, though it can also have negative impacts on health and safety, where concerns surround the compatibility with all or most of these road functions given the extra collection process over and above the normal cutting regime. Ensuring safe access and egress for maintenance workers using collecting machinery is paramount considering the varying land uses and slopes, though harvesting management programmes can be reviewed and incorporated into both Transport Scotland's and all local authority Roads Asset Management Plans (RAMP). Similarly, if the European end-of-waste regulations are applied, then verge cuttings would be considered a resource and not a waste and require collection. This regulatory approach would also present implications for public and open spaces throughout Scotland, and their associated maintenance budgets. However, the *status quo* among local authorities is not to take a pragmatic approach to grass cuttings as a resource. One reason for this approach may be the UK Government's reduced interest in renewable energy sources which is reflected in the current AD Feed-in-Tariff (6-7 pence per kWh). Therefore, it is important that AD plant operators keep running costs low and could consider grass cuttings as a local accessible feedstock.

Biodiversity conservation along Scotland's road network provides essential ecosystem services where unimproved grasslands support a thriving environment for valuable habitats. Human development both physical and agricultural has resulted in wild plants and animals relocating to less disturbing areas and highlights the importance of biodiversity restoration management plans. Cutting and collecting twice a year would support the development of food plants and biodiversity, where an early cut-and-collect mid-July would allow plants to flower and set seed. Additionally, where flora and species richness is generally poor, increasing the cutting frequency can remove the rank vegetation and prevent the build-up of nutrient from the cut sward, further promoting habitat quality [14].

The layout and design characteristics of many verges present further challenges where inaccessibility and ground conditions can impact health and safety. For instance, obstacles such as barriers, street lamps, and road signs can be problematic to cut around. It can be accepted that enhancing biodiversity and ensuring road user safety are the top priority functions of roadside management plans, though many urban areas receive cuts far greater than the 1.2 m swath indicated without affecting the local ecology and enhances the feasibility of adopting machinery that can cut 1.6 m swaths or greater.

Collection of grass cuttings as an AD feedstock is not a new concept and previous trials were conducted by Montgomery Wildlife Trust and Powys County Council and formed the basis for this study comparative analysis. Similarly, trials are ongoing between Lincolnshire County Council and Lincolnshire Wildlife Trust though information was unobtainable. Both trials have a common goal of economic and environmental gains in light of budget cuts. Yet, the issue persists of what to do with the collected material. Lincolnshire County Council proactively developed their own AD plant to take the material. For many Scottish local authorities, this initial outlay, and the lack of rural AD plants within a given distance for collection and deposition may stop any proposed scheme before it even gets started. However, increasingly farms are building small AD plants that operate on an input of manures and slurries [15]. It is also suggested that to operate economically and efficiently, farmers will need to consider additional feedstocks such as grasses [16].

The trunk road network makes up 3,507 km (2,719 miles), or six percent of Scotland's overall road infrastructure, supports the movement of people and goods, is vital to Scotland future success, and has a net asset worth greater than £20 billion. Similarly, the functions of the trunk road network are like local and rural roads except there is higher volumes of fast moving traffic and the potential to collect grass cuttings becomes more problematic than that of rural or residential roads and requires more planning and safety consideration.

Trunk road network operators (e.g. Mouchel and Bear Scotland) have experience across Scotland's trunk roads, many of their responsibilities interlink, and both play an important role in maintaining the trunk road network. Therefore, it was important to gain both their views regarding the collection of grasses and the implications as they see them. Both agree the biggest concerns surrounding grass collection would be increased traffic flows and practicality during access or egress; they agree, though, that the removal of cuttings would enhance biodiversity across the network. Mouchel had concerns about the use of bailing machinery on slopes given the steepness of sections of Scotland's terrain. They further emphasized concerns that Scotland's wet weather coupled with the slope would impact both safety and viability. Bear Scotland, on the other hand, accept there are challenges with access and egress but fully acknowledge that equipment exists to counteract such issues. Furthermore, while Mouchel have concerns over the steepness of the slopes, it can be accepted that it is only the initial flat 1.2 m swath that is being considered and would reduce the risk to health and safety. Machinery such as the integrated MULAG cutting and collecting vehicle, if utilized, would further improve efficient collection, mitigate the issue of access and egress; it would also reduce existing work activities, and would improve worker safety. Similarly, Mouchel suggest the use of new machinery would also result in cutting operations taking three times the time and causing additional traffic. However, equipment such as the MULAG can be operated as efficiently as current cutting operations while ensuring greater safety and the collection of material. Additionally, mini bailers offer an alternative collection method to the MULAG system and would require little change from current cutting program where the only variation is the collection of baled grass after cutting.

Scotland's trunk road network has a future role in promoting verge biodiversity and can be aided with the removal of cuttings. In part, the trunk road network can also work to enhance energy security through the collection or grasses and the production of biogas although, ultimately, it needs to be economically viable. However, grass management is a required operation that protects road user safety and the only additional cost is the collection; increasing the cutting regime along the trunk road network would also enhance the both viability and biodiversity. Therefore, it is important to attain further data and opinions that work towards feasibility trials.

6. Conclusions

Without competing with food production, grassed verges produce harvestable biomass as part of Scottish local authorities and trunk road contractors cutting regimes. Urban residential verge management regimes may be to cut up to 18 times per annum at priority junctions, roundabouts, and regions of interest. However, health and safety around the collection of cuttings presents the biggest obstacle. However, incorporating the latest cut-and-collect technology can reduce this concern.

The theoretical biomass resource along Scotland's road network was of the order of 270×10^6 m^2. Due to terrain variability, the potential availability of grassed verges for biomass collection decreases, the availability of biomass is likely to increase as often urban verges exceed the 1.2 m swath cut. Thus, increasing the swath cut to 1.6 m would increase biomass potential by 90×10^6 m^2, while further grass biomass can be gained through the inclusion of public and open spaces, and even from sports stadia.

Comparative statistical analysis showed that a 1.2 m swath cut would produce between 300 – 400 kg dry mass/km. Scotland's road network has 56,000 km times two annual cuts times either roadside and gives a total biomass potential of 67,200–89,600 tonnes dry mass/yr, with a biochemical methane yield of between $18{,}2 \times 10^6$ m^3 CH_4 - $24{,}3 \times 10^6$ m^3 CH_4. Moreover, increasing the swath cut to 1.6 m would potentially yield between $24{,}3 \times 10^6$ m^3 CH_4 - $32{,}4 \times 10^6$ m^3 CH_4.

Further research to evaluate the economic viability of this idea for Scotland's road network is needed. However, the sustainable treatment and bioenergy recovery potential locked in Scotland's road network offers a potential source of sustainable renewable energy, promotes a healthy verge environment, improves energy security, does not impact on food production, and reduces greenhouse gases as Scotland looks to achieve an 80 % emissions reduction by 2050.

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